tabulated the number of times rainfall occurred at the two stations within 3 hours, 4 to 6, 6 to 8, 8 to 12, etc., hours. For the LOWS the table is as follows:

LOW centered over—	Hours interval between rain beginning at Nantes and Le Mans			
	0-3	4-6	6-8	8-12
1. British Isles	38	12	2	11
2. Netherlands	12	15	.....	3
3. Norway, Iceland, Stornoway	10	5	4	1
4. Brittany, Straits of Dover, Western France	2	13	4	7
5. Sweden, Baltic Sea	7	.....	2	.....
	69	45	12	22

For HIGHS the following is the result:

HIGH centered over—	Hours interval between rain at Nantes and Le Mans			
	0-3	4-6	6-8	8-12
1. Spain, Gascony	36	12	11	7
2. Central Europe	30	5	21	4
3. Great Britain (with LOW over North Sea)	6	4	2	.....
4. Southeast of Europe	2	6	.....	2
	74	27	34	13

It is thus seen that the shorter interval, 0 to 3 hours, seems to prevail. At the time of the rainfalls which were compared, the winds in the most cases were from NW. to SSW. Similar studies were made for the interval between Brest and Le Mans, with the following result:

LOW centered as in—	Hours interval between rain at Brest and Le Mans			
	0-6	6-8	8-12	12-15
1 above	11	6	6	1
4 above	3	1	2	.....
5 above	4	1	1	.....
	18	8	9	1

HIGH centered as in—	Hours interval between rains at Brest and Le Mans			
	0-6	6-8	8-12	12-14
1 above	9	4	6	1
2 above	6	.....	.....	.....
3 above	3	2	2	.....
4 above	.....	3	.....	.....
	18	9	8	1

Here, too, the prevailing interval is the shortest one, and the winds, says the writer, are the same as in the previous case. The distance between Nantes and Le Mans is 185 kilometers, and between Brest and Le Mans is about 420 kilometers.—*C. L. M.*

THE MOST INTENSE RAINFALL ON RECORD.[1]

By BENJAMIN C. KADEL.

Mr. H. G. Cornthwaite's article, "Panama Rainfall," in May, 1919, MONTHLY WEATHER REVIEW, 47: 298–320, contains in Table 1, Maximum rainfalls, a statement of the occurrence of 2.48 inches of rainfall in 5 minutes at Porto Bello, Panama, 2:07 a. m., November 29, 1911. The actual record has been kindly loaned to the Weather Bureau (see retouched photostat, fig. 1), and from it we learn that all but 0.01 inch fell in three minutes, or at a rate of 0.82 inch per minute. As this exceeds by 100 per cent the rate of 8.07 inches in 20 minutes at Curtea de Arges, Roumania, July 7, 1889, heretofore considered the world's record, it is desirable to record such facts as may have a bearing upon its validity.

The shower that includes the period under consideration fell at an excessive rate from 12:45 a. m. to 2:45 a. m., the total fall for the two hours exceeding 6 inches. The total rainfall for the 24-hour period ending at 5 p. m. was 7.60 inches by stick measurement. The 12-inch tipping bucket registering gage apparently functioned properly throughout the period, although the record for the three minutes is so blurred as to be illegible, the blurring being due to the slow clock speed rather than to instrumental failure. The actual fall during the period was determined by first correcting the legible portion of the 24-hour record on the basis of the previous performance of the gage, and in accord with accepted practice, then crediting the remainder to the excessive period. It is established by letters of inquiry, addressed by Dr. Brooks to Mr. Cornthwaite, that the gage was emptied at 5 p. m. before the rain began; that the instrument was in the hands of careful observers; that to enter both stick measurements and registration was the usual practice; that the water was regularly poured out at each observation; and that no foreign substance was found in the rain gage or in the funnel at the time the rain was measured. The record was promptly made the subject of special inquiry, and the officer in command states that in his opinion it is correct. Persons who were at work at the time remarked about the heavy rain, and low-lying ground was covered with several inches of water, drains not being capable of carrying it away as fast as it fell. Several large boulders were dislodged and washed down the hillsides, and the reservoir supplying the town with water overflowed. The record therefore appears to be well substantiated.

While the evidence supporting the validity of the record is sufficient under ordinary circumstances to warrant acceptance, it appears proper to set forth in this connection some reasons for doubting that the actual quantity of rain fell within the three minutes. The method of interpreting the record by the process of elimination means that any failure of the tipping bucket to register throughout the entire 24 hours would be credited to the three-minute period. Dr. Brooks counted 13 or 14 projections on the original record, which probably means 13 or 14 excursions of the zigzag pen, corresponding to 1.30 or 1.40 inch. The record is too blurred to be sure of more ups and downs. This agrees fairly well with the performance of a tipping bucket during an experiment at this office, during which 2.48 inches of water was poured into a similar rain-gage funnel, after which the lower end of the funnel was opened. The time required for the water to flow through the opening was 2 minutes and 15 seconds, and the tipping bucket made 194 tips during the process. The performance of the bucket was decidedly erratic, especially at first. Now, since the time occupied in discharging 2.48 through the small opening at the lower end of the funnel is nearly as

[1] Paper presented at meeting of the American Meteorological Society, Washington, D. C., Apr. 22, 1920.

great as the time occupied by the excessive rainfall record, the question is raised as to whether some foreign substance may have become lodged at the bottom of the funnel, so that the flow was practically shut off for some time preceding the record, and the accumulated pressure of the water finally forced out the obstruction, and the water all rushed through in three minutes. This interpretation of the record is strengthened by its appearance during the 17 minutes preceding, when the rain, which had been falling at a heavy rate, slackened. Another possibility mentioned by the observer in charge is that some one may have poured a quantity of water into the gage, although the chances of anyone having done so at 2 a. m. during a tropical rainstorm are remote.

Dr. H. C. Frankenfield has suggested hailstones as a possible means of closing the gage for a time.

EXTRACTS FROM CORRESPONDENCE.

In reporting the rainfall of November, 1911, at Porto Bello, Panama, Mr. John H. Poole remarked:

There was a young cloudburst at about 2:00 a. m. [Nov. 29], we were unable to properly count the amount registered.

Poole. 11/30/11.

Mr. C. M. Saville, on receiving the automatic record, figured by elimination that the amount had been 2.46 inches in three minutes between 2:07 and 2:10 a. m. Further information was requested from Mr. Poole, who replied as follows:

PORTO BELLO POLICE STATION,
December 11, 1911.

MR. C. M. SAVILLE,
Assistant Engineer, Culebra, Canal Zone.
(Through Chief of Police, Ancon.)

SIR: Replying to your letter of the 8th instant, relative to heavy rain at this place on the night of November 28-29th, I have the honor to state that at about 8:00 a. m. on the 29th ultimo, first-class policeman Anthony J. Lechler, #108, Zone Police, who was on duty from midnight the 28th to 8:00 a. m. the 29th, informed me that there had been an extra heavy rainfall during his tour of duty; he also called my attention to the rainfall record sheet. I examined the gage and register, found that there was nothing apparently wrong, that nothing had been tampered with so far as I could learn. I then measured the water in the tank and found the amount as recorded by me on report of the 28-29th ultimo. It is possible that some one could have poured a bucket of water into the tank, but I am of the opinion that such is not the case. In my opinion the records are correct.

Several persons who were at work at the time have remarked about the heavy rain that fell that night. The low ground in the vicinity of the machine shop, district quartermaster's office, and police station was covered with several inches of water during the hard rain, drains not being capable of carrying it away as fast as it fell.

Very respectfully,

JOHN H. POOLE,
Corporal #18, Zone Police, Police Officer in Command.

The following letter was received, dated Balboa Heights, C. Z., October 3, 1919:

DEAR MR. BROOKS: Replying to your inquiry regarding the maximum rainfall record at Porto Bello, the automatic record, together with copies of the correspondence on the subject, are inclosed herewith. In addition to the information contained in this correspondence, it may be stated that several large boulders were dislodged and washed down the hill sides and the reservoir supplying the town with water overflowed during this rainstorm.

The automatic record was accepted as probably approximately correct for the following reasons:

(1) The policemen at Porto Bello had always been accurate and reliable observers.

(2) The rain gage was located on the slope of a clayey hill about 100 feet back and 30 feet above the floor of the police station in a position difficult of access except thru the police station (see fig. 2).

(3) The heaviest downpour occurred at about 2.00 a. m., in the midst of a period of heavy rainfall at a time of the night when the gage could not have been tampered with except with *malicious intent*, and with considerable personal inconvenience to the perpetrator.

(4) The *variable rates* of rainfall immediately preceding and following the period of heaviest fall indicate that the funnel of the gage could not have been stopped up, causing the water to accumulate in the upper section of the gage.

It will be noted that the amount of rainfall during the period of maximum fall was determined largely by elimination, subtracting the rainfall during the remainder of the storm from the total amount collected in the gage to determine the amount during the period of maximum fall when the record was indistinct, the automatic record being corrected on account of the excessive rate of fall.

Summarizing, it would seem that this record is approximately correct, unless some one with malicious intent falsified it by pouring a quantity of water into the gage, but it seems hardly likely that anyone would get up at 2.00 a. m. in the midst of a heavy tropical rainstorm, climb a slippery clay hill back of the police station, and pour a bucket of water into the rain gage as a practical joke, and then remain forever silent on the subject to escape detection.

* * * * * *

Very respectfully,

H. G. CORNTHWAITE,
Assistant Chief Hydrographer.

This was followed by a letter to Mr. Cornthwaite December 2, 1919, excerpts of which follow:

* * * * *

Several of us have given it careful scrutiny, and the following questions have been raised:

1. What had been the performance of the rain gage immediately preceding these dates, i. e., how many tips did the bucket make relative to the measured amounts on other occasions when the rainfall was so heavy as the 1-inch-in-20-minutes rates found on the sheet before me? I presume that the previous performance was the basis for the corrections applied to the record at hand.

2. Was there any water in the gage not poured out at 5 p. m. the 28th?

3. What can you say as to the possibility of a slight obstruction having become lodged in the funnel for the 17 min. preceding the blurred record? This period had only 0.13 in. recorded.

4. Were there any reports of such an exceptional downpour having been noticed after the few minutes of quiet that preceded it?

I have been able to count 12 top and bottom tips, indicating 1.19 of record in the period between 2:07 and 2:10 a. m., and there seems almost certainly to be 13, and possibly 14. Unless there is some systematic error in the record as a whole, e. g., the record of 0.01 in. when, say, 0.012 fell into the bucket before each tip started, it would seem unlikely that the error of registration was as great as 1 inch in this cloudburst. An experiment made here with 2.48 poured into the funnel all at once showed some erratic action, but the water went through in 2 min. and 15 sec. and the bucket tipped 194 times. The record looks very much like the Porto Bello one.

* * * * *

Very respectfully,

CHARLES F. BROOKS,
Meteorologist-Editor.

The following reply came:

BALBOA HEIGHTS,
December 16, 1919.

MR. CHARLES F. BROOKS,
Editor Monthly Weather Review, Washington, D. C.
(Through Chief Hydrographer.)

DEAR MR. BROOKS: Answering your questions regarding the Porto Bello rainfall record:

1. Yes; previous performance was the basis for the corrections applied to this record. An excessive shower on November 12 showed 1.29 inches by register and 1.43 inches by stick. A shower on November 22 showed 1.50 inches by register and 1.65 by stick. It is my belief that a somewhat larger correction was applied to the November 28-29 record on account of heavier rate of rainfall.

2. No. Rainfall at Porto Bello preceding this heavy rain was light. 5:00 p. m. November 26, 0.10″ by register, 0.09″ by stick; November 27, 0.11″ by register, 0.10″ by stick; November 28, 0.08″ by register, 0.07″ by stick. It will be noted that the register and stick measurements disagree slightly, indicating that the water was drawn off and *actually measured* each day. Had it been poured back into the gage, the totals would have been progressively larger day by day, and the three days' total amounts only to 0.26 inch.

3. This is thought to be possible but not probable. Rain-gage funnels here have been obstructed several times during the past 10 years by (1) cinders, or (2) bird guano, but *in no case has the obstruction been complete* and *in no case has it cleared suddenly*. In every case that has come to our notice the water has seeped through slowly, making a record almost as regular as an unbroken sunshine record, but at a slower rate.

There was no possibility of obstruction by cinders at Porto Bello and no foreign substance was found in the rain gage or funnel at the time the rainfall was measured.

4. Unfortunately the portion of the November 29th rainfall record under consideration occurred during the night (about 2 a. m.) when the

inhabitants of the village were in bed. So far as known no one noticed the period of quiet immediately preceding the heavy downfall.

Waterspouts have been observed along both coasts in Panama. It is not known whether such a phenomenon would be likely to occur at night.

Experiments here in pouring water into the raingage funnel gave a record approximately the same as you report. We were not able, however, to count the top and bottom tips, due to the blurred character of the record.

As previously stated, the Porto Bello maximum rainfall record, *although not entirely above suspicion*, was accepted as probably approximately correct. If the blurred portion of the record is *not genuine*, the malicious pouring of a quantity of water into the raingage was thought to be the most plausible explanation.

Porto Bello has experienced some very heavy rains. The rainfall station there was not in operation from August, 1914, to December, 1918, but the following newspaper report of a heavy downpour on the night of May 4–5, 1918, illustrates the excessive character of the rainfall.

"HEAVY RAINFALL IN PORTO BELLO.

"Reports from Porto Bello are to the effect that on the 5th of May (1918), a torrential downpour occurred in that town and vicinity, causing a number of land slips on the adjacent hills and considerable damage to growing crops. All of the creeks overflowed, and the water invaded the streets of the village. Some of the houses in Porto Bello are reported to have been destroyed by the inundation. The new telephone line suffered some damage through the rushing waters having overthrown trees, which fell across the line. It is said that such a rainstorm as the village just experienced is the greatest within the memory of the oldest inhabitant. No lives were lost."—(*Star* and *Herald*.)

Respectfully,

H. G. CORNTHWAITE,
Assistant Chief Hydrographer.

DISCUSSION.[2]

There was considerable discussion of this paper. J. Warren Smith told of how, in a cloudburst in Ohio, in which 7 inches of rain fell in half an hour, people who were out in it said that they were almost drowned and had to hold their hands over their faces to get air. S. P. Fergusson asked if there could be such rapid condensation in the atmosphere. C. F. Brooks thought that the 17-minute period of slack rainfall preceding the cloudburst was a necessary accompaniment to such an excessive rainfall, for the rate of rainfall much greater than any possible rate of condensation indicated that there must have been strong upward currents holding the raindrops up in the air, and that therefore there must have been downward current and little rainfall about the region of up-rush. H. C. Hunter called attention to the rainfall at Guinea, Va., in which 9 or more inches fell in less than 45 minutes (MONTHLY WEATHER REVIEW, 1906, Vol. 34, pp. 406–407, 2 figs.). W. J. Humphreys elaborated on the explanation of a cloudburst outlined by Dr. Brooks (see above). "Could hail have occurred?" asked Mr. Kadel. C. F. Talman called attention to the fact that hail is known in the tropics, especially in India, and that it had been reported in the mountains of Haiti and in Jamaica. Dr. Brooks called attention to the fact that most of the Indian hail occurred in the arid and semiarid parts of subtropical northwestern India, and after raising the question as to whether the Jamaica hail was not in the mountains, stated that it appeared extremely unlikely that hail would ever fall at sea level in Panama. [*Note:* An article by H. G. Cornthwaite, on "Panama thunderstorms" (MONTHLY WEATHER REVIEW, Oct., 1919, Vol. 47, pp. 722–724) mentions the occurrence of hail in the Canal Zone on three occasions in 12 years.] Mr. Kadel said that where such intense rainfalls occur, the gages should have greater capacity in the tipping bucket.

[2] Reprinted from *Bull. Amer. Met'l Soc.* May, 1920, vol. 1, no. 5, p. 52.

SUNSHINE AND CLOUDINESS IN THE CANAL ZONE.

By H. G. CORNTHWAITE, Assistant Chief Hydrographer.

[Balboa Heights, C. Z., Apr. 21, 1920.]

The degree of daytime cloudiness in the Canal Zone is less during the dry season than in the rainy season, but even in the dry season the sky is by no means cloudless, the average degree of daytime cloudiness being about 50 per cent of the sky obscured in the dry season and about 75 per cent of the sky obscured in the rainy season. There is not the intense unobstructed solar radiation in the Canal Zone that is experienced in dry sections of the United States. The cloudless skies so common in the semiarid sections of southwestern United States are practically unknown in the Canal Zone.

March is generally the month of minimum cloudiness in the Canal Zone, while June and November are usually the months of maximum cloudiness and least sunshine. The maximum *duration* of sunshine occurs during the dry season, usually in January, and the maximum *intensity* occurs in March or April.

The daytime cloudiness is somewhat greater in the interior and over the Pacific section than on the Atlantic side. The prevailing winds during the greater part of the year blow from off the Atlantic. These winds reach the isthmus with water vapor mostly uncondensed, and therefore not visible as clouds. In crossing in the Isthmus a large part of the water vapor carried by these winds is condensed and becomes visible as cloud, the most effective agents of condensation being the ascending air currents that develop over the excessively heated land surface and the upward deflection of the winds approaching and passing over the Continental Divide. Any increase in elevation of a mass of air, from whatever cause, results in a corresponding decrease in its temperature. When the temperature of the ascending air current has been lowered to the dew point, its invisible water vapor condenses and becomes visible as cloud.

Night cloudiness—No actual records are available of nighttime cloudiness, but in general the cloudiness is much greater during the daytime than at night. This is especially noticeable during the dry season, when heavy cumulus clouds form regularly during the daytime, and as regularly disappear with the approach of night.

Over the interior night cloudiness often takes the form of fogs, which are numerous during the rainy season, but which usually lift or dissipate before 8.30 a. m. Few fogs occur along either coast in the vicinity of the Canal Zone. (See fig. 2.)

During the rainy season night and early morning cloudiness is heavier along the Atlantic coast, where approximately half of the total rainfall occurs during the nighttime.

Monthly extremes.—The maximum monthly daytime cloudiness recorded during any one month of the past 12 years was 93 per cent at Colon in July, 1914, and the least average monthly cloudiness was 30 per cent at Balboa Heights in February, 1918.